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ENHANCING SENSITIVITY TO VISUAL MOTION.(U)
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May 1980

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ENHANCING SENSITIVITY TO VISUAL MOTION

Robert Sekuler

Prepared For:

Air Force Office of Scientific Research
Air Force Systems Command
United States Air Force

Cresap Neuroscience Laboratory • 2021 Sheridan Road • Evanston, Illinois 60201 • (312) 492-7406

81 2

REPORT DOCUMENTATION PAGE

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1. REPORT NUMBER AFOSR-TR- 81-0090	2. GOVT ACCESSION NO. AD-A094 793	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) ENHANCING SENSITIVITY TO VISUAL MOTION		5. TYPE OF REPORT & PERIOD COVERED Final
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Robert Sekuler		8. CONTRACT OR GRANT NUMBER(s) AFOSR-79-0064
9. PERFORMING ORGANIZATION NAME AND ADDRESS Department of Psychology, Northwestern University, Evanston, Illinois 60201		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 61102F 2313A2
11. CONTROLLING OFFICE NAME AND ADDRESS Air Force Office of Scientific Research (NL), Life Sciences Directorate, Bolling Air Force Base, D. C. 20332		12. REPORT DATE May 1980
		13. NUMBER OF PAGES 35
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

motion perception; training; reaction times; detection; signal detection; vision; perception; human factors; engineering psychology; practice

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report reviews a one-year investigation of techniques that might enhance an observer's sensitivity to moving targets. The five experiments reported here cover a broad range of such techniques. Experiment I measured direction difference thresholds as a function of target velocity for 39 observers. Despite large (nearly fourfold) individual differences in thresholds, it was clear that ability to tell what direction a target moved

20. in depended strongly on its velocity. In addition, this ability was seriously degraded for an oblique direction compared to performance with upward motion. Experiment II showed that this variation in threshold with target velocity was independent of the distance traveled by that target. This finding contradicts one common theory of motion perception. Experiment III measured difference thresholds for direction at various points in the course of training with a reaction time task. This task required observers to respond rapidly to moving targets presented after exposure to broadband or filtered directional noise. The reaction times to motion onset decreased with practice but the direction difference thresholds did not show any comparable change. Experiment IV examined the effect of practice on the performance deficit produced by an observer's uncertainty about the direction in which a to-be-detected target would travel. The range of possible directions was broad, covering 360 degrees. The effects of stimulus uncertainty were stable over the five sessions of practice. Experiment V examined whether practice could reduce the effects of direction uncertainty when the range of possible directions was narrower than that used in Experiment IV. Here three different, narrower ranges were used: 40, 80 and 120 degrees. Repeated testing reduced the detection losses normally associated with direction uncertainty. Though practice did not eliminate such effects entirely, it did enhance performance considerably. This improvement occurred rapidly, eliminating differences among the three different ranges of directions.

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INTRODUCTION

Traditionally, work on human vision has emphasized the striking homogeneity of performance among various observers. Among the historical reasons for this emphasis are explanatory models based on optical and neural factors which are assumed to be quite homogeneous among observers. With the exception of distinctly anomalous (e.g. color defective) observers, it has been assumed that the physiological underpinnings of various visual effects were fairly uniform from observer to observer. As a result, individual differences in visual abilities have not been given serious, sustained attention (DAVIDOFF, 1975).

Recently, developments in neurophysiology have begun to change attitudes toward individual differences in vision. These developments include the demonstration that experience, notably but not exclusively the experience of young observers, can drastically alter the perceptual capacities of those observers (BARLOW, 1975; COHEN & SALAPATEK, 1975). In fact, differential experience provides a possible physiological basis for stable and significant individual differences in visual abilities. For example, rearing newborn kittens so that they only see contours of one orientation alters the orientation sensitivities of cells in their visual cortices and also affects their ability to see contours of various orientations (BARLOW, 1975). Other studies have reared young animals in environments containing unusual distributions of visual motion. For example, CYNADER, BERMAN & HEIN (1975) reared cats in an environment in which irregularly shaped targets moved constantly leftward. Single cell recordings revealed that unlike normally reared cats, most cortical neurons in these animals responded optimally to leftward movement or movement approximately leftward. Similar results have been reported by others (e.g. FLANDRIN & JEANNEROD, 1977).

For ethical reasons, most of the related work with humans has been restricted to taking advantage of the existence of observers who have suffered accidental visual deprivations of one sort or another. For example, observers with severe, uncorrected astigmatism suffer a relative deprivation of exposure to contours in one set of orientations (FREEMAN, MITCHELL & MILLODOT, 1972). There is reason to believe that this relative deprivation, based on an optical error, leads to neural alterations of the visual cortex (FREEMAN & THIBOS, 1975).

Recently, two investigators (GINSBURG, 1977; DeVALOIS, 1977) offered strong evidence that in adult humans, relatively small amounts of special exposure can alter visual sensitivity drastically. Working independently and on somewhat different problems, each found that small amounts of experience with grating targets can produce drastic changes in subsequently measured visual sensitivity. GINSBURG found that for certain amblyopes, repeated testing enhanced sensitivity several fold. Amblyopia refers to any of a class of diseases in which there is a loss in visual acuity or visual sensitivity without a concomitant optical defect. With normal observers, DeVALOIS found that over one year's testing, the threshold contrast required to see some gratings declined by as much as a factor of eight.

In addition to enhanced contrast sensitivity, DeVALOIS (1977) found another interesting effect of visual experience on spatial information processing. It is known that adaptation to a high-contrast sinusoidal luminance grating produces a temporary, band-limited loss in sensitivity centered around the adaptation spatial frequency[1]. The band of spatial frequencies over which sensitivity is diminished

[1]Spatial frequency, for a grating pattern, is defined as the number of cycles (dark and light bars) in one degree visual angle.

has provided an estimate of the spatial selectivity of certain human cortical analyzers. But DeVALOIS discovered that repeated practice narrowed the band of test spatial frequencies for which exposure to a high contrast grating reduced sensitivity. This narrowing could be explained, she noted, "if one assumes that detection is based on a pooled response of many cells which differ in their characteristic frequencies and bandpass characteristics. If, with increasing practice, a subject simply becomes more efficient at restricting the sample pool to those which are most sensitive to the frequency being observed, then one might expect that the amplitude of the adaptation effect would increase. If those cells are also narrower in their sensitivity range, then the bandwidth of the effect should also decrease. This would be, in essence, selectively attending to different types of detectors (p. 1064)."

The work of GINSBURG & DeVALOIS is particularly important for two reasons. First, the visual ability they studied, contrast sensitivity, has a fairly well understood physiological basis (MacLEOD, 1978); second, their observations with humans correlate well with earlier demonstrations that visual experience alters the spatial frequency responsivity of various neural elements in non-human animals. As a result, the work of GINSBURG & DeVALOIS provides a theoretically solid basis for other, more detailed investigations of experiential effects on the vision of adult humans. Finally, by showing that differences between the visual sensitivities of observers can be reduced by appropriate experience, the work of GINSBURG & DeVALOIS also suggests that differential experience might actually give rise to inter-observer sensitivity differences.

Differential experience is also implicated in some recently noted individual differences in motion sensitivity. As part of a larger study, BALL & SEKULER (1979) found two observers who differed markedly in their abilities to 1) detect upward moving targets in the presence of visual noise, and 2) to detect small changes in the direction in which targets move. These observations will be discussed in detail later. For the moment we need only note the circumstantial evidence that these performance differences were in part due to differential experience with moving targets. The observer with greater sensitivity in each case, had nearly ten times as much exposure, in the laboratory, to moving targets like those used by BALL & SEKULER.

Since analysis of visual motion is important in a variety of tasks in visually guided flight we should follow-up these observations by identifying the full range of motion sensitivities in the population. If our hypothesis were correct and individual sensitivity differences were related to differential amounts of visual experience, it should be possible to enhance the sensitivities of observers by providing exposure to appropriate stimuli.

<u>Direction difference threshold</u>. Two related studies from Northwestern provide the immediate context for this research. The first study involved the measurement of direction difference thresholds (hereafter, DDTs) (BALL & SEKULER, 1979). These thresholds index an observer's ability to detect small changes in the direction in which visual targets move. The targets were computer controlled patterns of spatially random dots. The dots could be translated as a sheet (i.e., in fixed spatial phase) in any desired direction. At any one time about 500 dots were visible behind an 8° circular aperture. Trials consisted of two, 600 msec intervals, separated by 1 sec. In the first interval the pattern of dots on the CRT moved directly upward; in the second interval the dots moved in any one of several different directions, ranging from 2 degrees counterclockwise to 2 degrees clockwise of upwards. At other times the CRT screen was blank. The observer's job was to judge the direction of motion in the second interval relative to the first. Figure 1

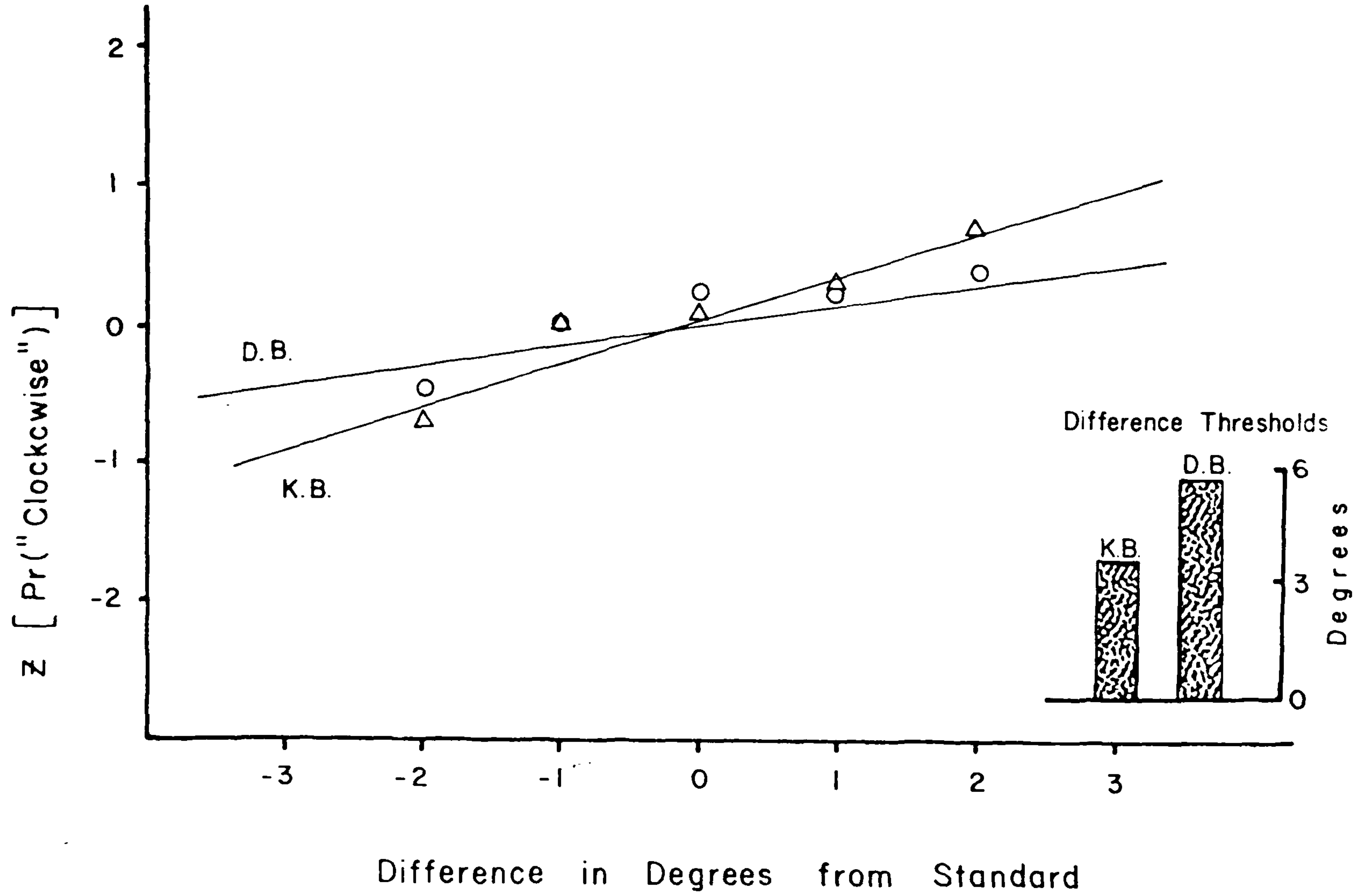

Figure 1. Direction difference thresholds for 2 observers using method of constant stimuli.

shows for two observers how performance varied with the difference between directions in the intervals in each trial. The Y-axis gives the Z-score associated with the present "clockwise" judgments; the X-axis ranges from the most counterclockwise to the most clockwise stimulus. The lines on the figure are the least-squares best-fitting lines. Note that for observer K.B., performance changes rapidly; for observer D.B., performance changes more gradually. The slopes and associated 95% confidence limits are 0.30 ± 0.08 and 0.02 ± 0.05, for observers K.B. and D.B., respectively. In fact, the difference in slope of the two lines is statistically significant ($p<.01$). The inset puts this another way, giving the difference thresholds for the two observers. Observer K.B. is able to correctly recognize much smaller differences in direction than is D.B. These individual differences in ability to tell in what direction something moves are quite stable and show up in other tests too.

Reaction time measure of directional selectivity. The same observers were also used in another, parallel study of motion sensitivity (BALL & SEKULER, 1979). On any trial, observers first saw randomly oscillating dots. The 400 dots moved sharply in one direction after another. The directions in which the dots move were randomized, with nearly all possible directions being equally represented. After a 1-2 second exposure to this random noise, the dots began to move continuously in one direction (say, upward). The observer's task was to hit a telegraph key, signalling that he detected the unidirectional motion. The random noise which came before the unidirectional motion, increased the reaction time to the motion by about 40-50 msec compared to control reaction times of 200 msec. This is a kind of visual masking, in which exposure to the pandirectional noise reduce the detectability of the test motion.

BALL & SEKULER then filtered the noise digitally, preventing certain sets of directions from occurring in the set of random oscillations. This created a noise stimulus in which all directions of movement were present except for a set proximate to upwards. Compared to the completely random, or broadband directional noise, noise which has no components at or near upwards had less effect on the observer's ability to detect the upward test motion. By varying the set of directions which are filtered out of the noise, BALL & SEKULER determined how various directional components in the noise affected the ability to detect upwards motion. Figure 2 and 3 show the outcome for two observers. Incidentally, the curves labelled "drift" and "no drift" represent noise conditions produced by two slightly different computer algorithms, the difference between which is trivial for our purposes here.

For both observers, as the set of directions which is filtered out of the noise is increased, the reaction time decreases. This reflects the fact that noise components which are quite different from upwards (e.g., downwards or rightwards) do not contribute much to the masking effect which the noise exerts on the visibility of upward motion. The rate at which reaction time decreases with an increase in the components removed from the noise, describes the direction tuning of mechanisms sensitive to upward motion. I should note that a similar procedure has been used in audition to study frequency selectivity.

Note the difference between the two observers. For D.B. (Figure 2), reaction time decreases slowly as a larger set of directions is removed from the noise; for K.B. (Figure 3), reaction time decreases more rapidly. As a result, we may say that K.B. exhibits sharper directional selectivity than does D.B. This outcome is consistent with the relative sizes of their difference thresholds (Figure 1).

The unresolved question of interest is: Can we do something to change an individual's ability to judge small differences in direction? We felt that it might

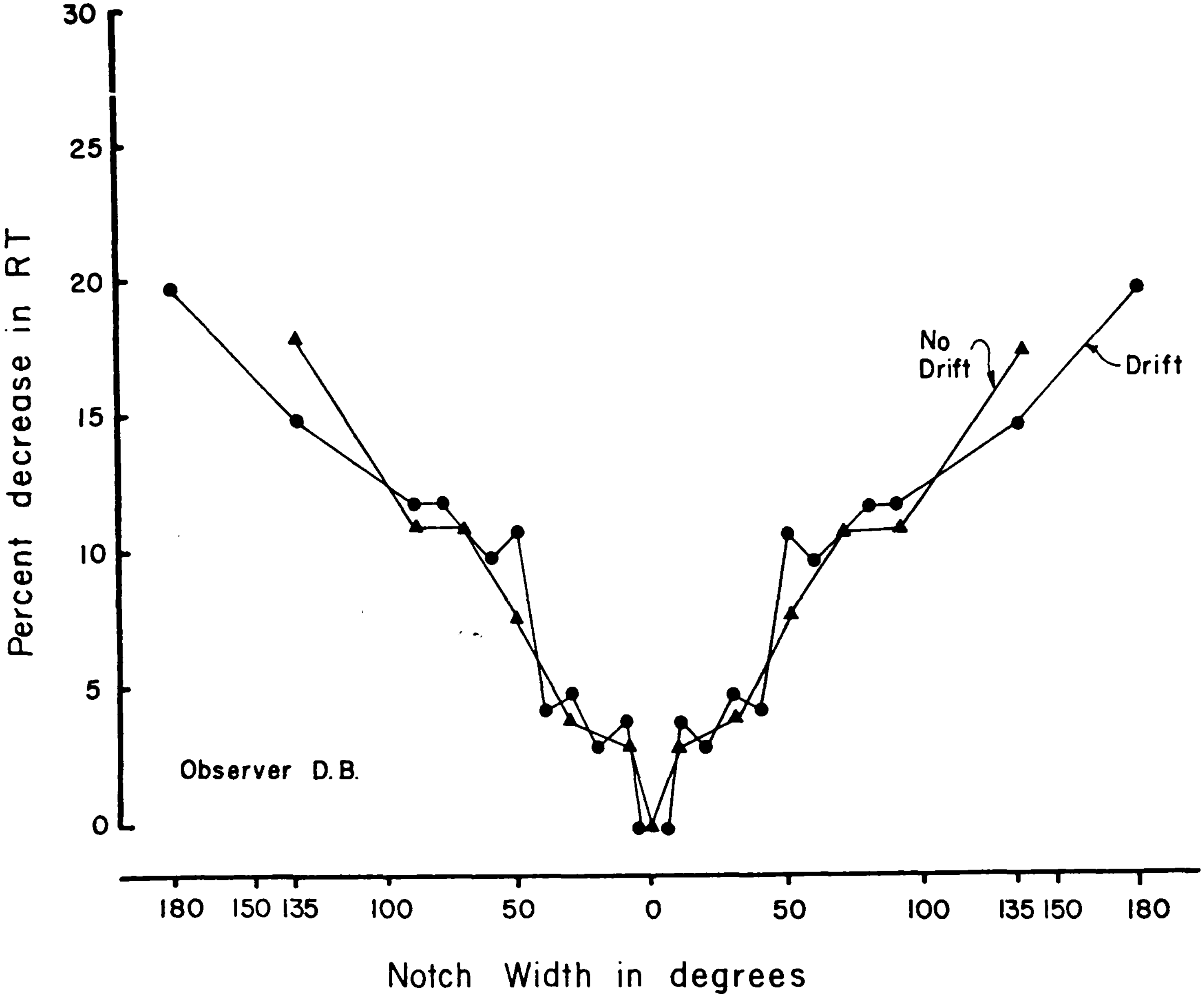

Figure 2. Change in reaction time to upward motion as a function of noise band filtered out of masking stimulus (observer D.B.)

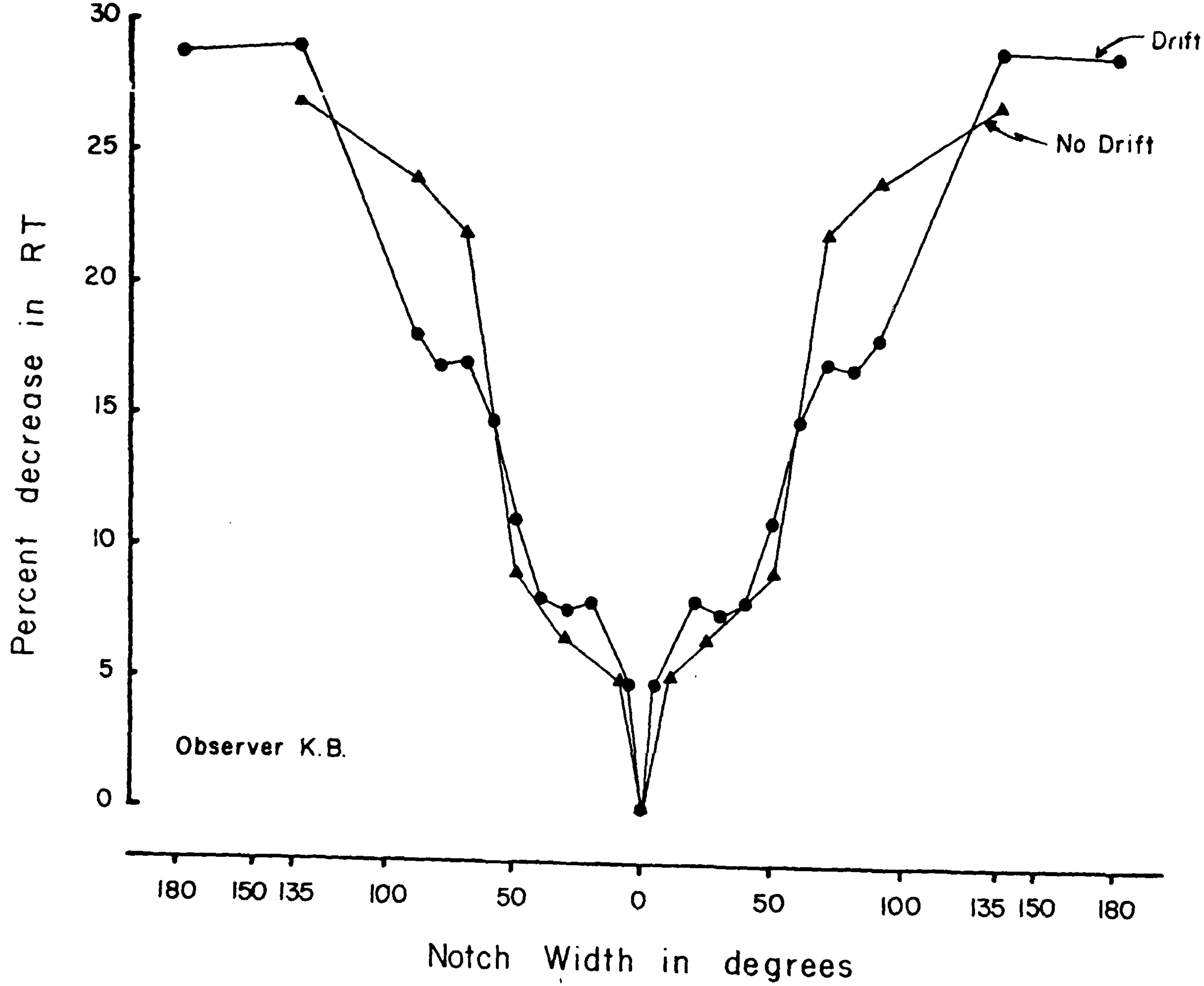

Figure 3. Change in reaction time to upward motion as a function noise band filtered out of masking stimulus (observer K.B.)

be possible to develop training procedures which could sharpen up a pilot's ability to distinguish small changes in direction and/or speed of visual motion. In our case, the observer (K.B.) with the better sensitivity to small differences in direction had a good deal of prior experience in a number of related studies; the other observer (D.B.) had nearly none.

EXPERIMENT I

DIRECTION DIFFERENCE THRESHOLDS

In order to establish the range of direction sensitivities for a large population of observers, direction difference thresholds (DDTs) were measured for 39 young volunteers.

Procedure. Observers sat in a darkened chamber and were instructed to fixate the center of a cathode ray display. The display subtended 8 degrees diameter; it had a constant veiling luminance of two candelas per meter squared. The stimuli were moving sheets of random dots consisting of incremental luminance superimposed on the constant veiling background. The luminance of the dots was adjusted to be approximately 50 times detection threshold for the observers (constrast equal 3.2). On each presentation, the dots moved in fixed spatial phase across the cathode ray display. Opposite ends of the display were functionally connected so that a dot disappearing off one end of the display would be re-presented at the opposite end. At any one moment approximately 500 of these random dots appeared on the screen. A specially designed, highly efficient tracking procedure was used to measure DDTs. Each trial consisted of two display intervals. Each interval lasted 360 msec.; intervals were separated by 500 msec. In each session we measured DDTs for seven randomly ordered conditions: upward motion at six different velocities (0.5, 1, 2, 4, 8 and 16 degrees per second) as well as oblique motion (45 degrees direction) at 2 degrees per second. To describe the procedure, consider conditions on which a DDT was measured for upward motion at 4 degrees per second. Each of two intervals per trial contained motion of 4 degrees per second. In one of the two intervals, chosen at random, motion was upward; in the other interval the motion was either clockwise or counterclockwise relative to upward. The difference between the two directions was systematically changed over the course of a set of trials (defining a track) until the observer reached a criterian level of performance. At the beginning of each track the difference between upward and nonupward directions was 10 degrees. This difference decreased or increased over the course of a track using a standard staircase technique. On each trial the observer had to indicate with a switch throw that interval, 1st or 2nd, which contained the upward motion. If the observer was correct, on the next trial the difference between upward and nonupward direction would be decreased; if the observer were not correct, on the next trial the difference would be increased. The amount by which the difference between directions was changed decreased over the course of the track. Prior to the first reversal the step size was 3 degrees; after each reversal the step size could change. The steps used in a single track were 3 degrees, 3 degrees, 2 degrees, 2 degrees and 3 final steps of 1 degree each. The DDT was defined as the difference between directions on the last 6 reversals. For each

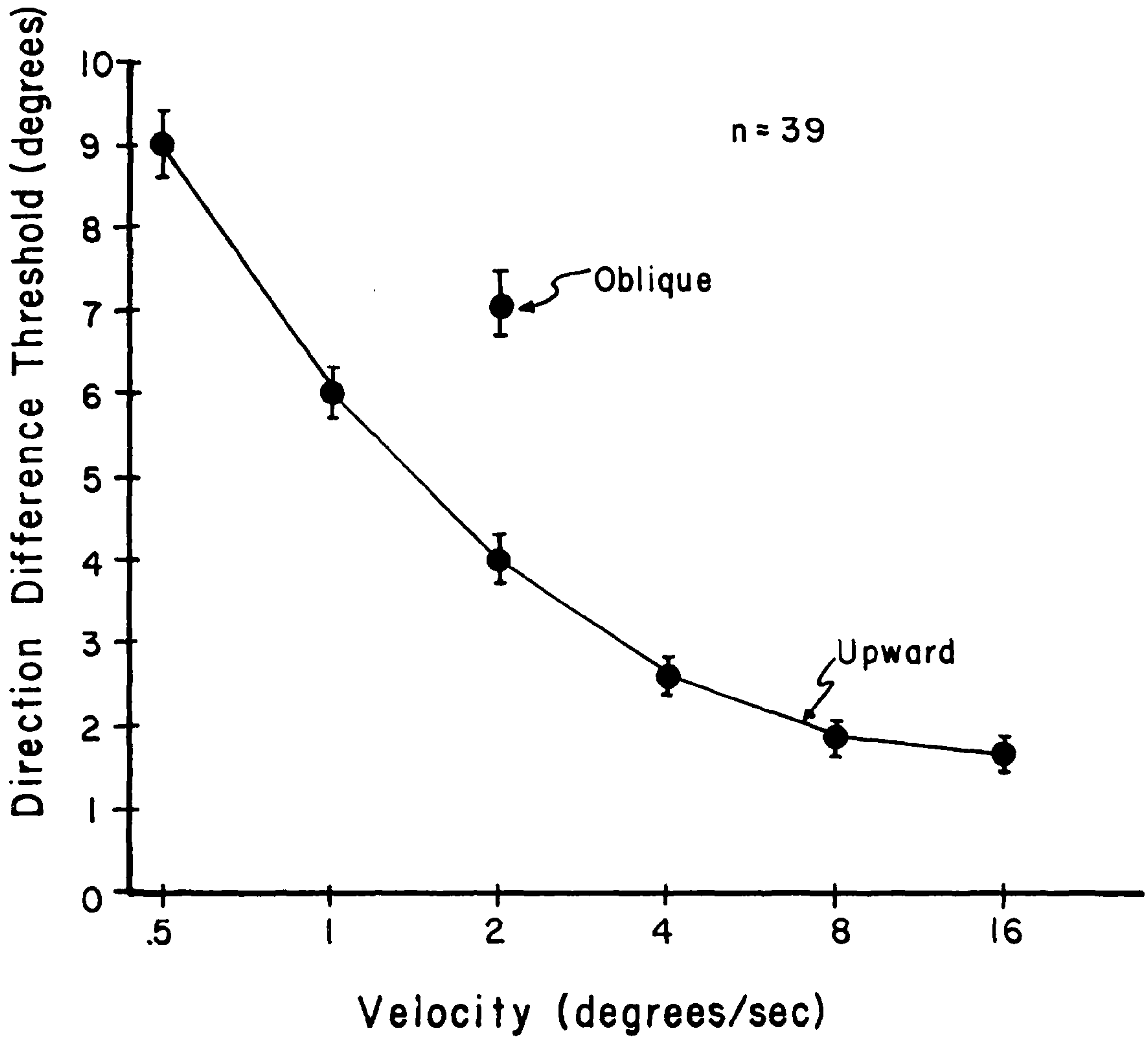

Figure 4. Direction difference threshold as a function of stimulus velocity for upward motion and oblique motion. Data are means of 39 observers.

condition and observer we measured 3 separate DDTs. An analogous procedure was used to measure the DDT at 45 degrees at 2 degrees per second.

As expected, individual differences on the DDT were substantial. For all 7 test conditions, the most sensitive observer had a DDT approximately one fourth that of the least sensitive observer. Figure 4 shows the mean DDTs as a function of stimulus velocity for all 39 observers. Observers were college student volunteers (average age 20; visual acuity, measured with a Bausch and Lomb orthorater, equal 1.0; Snellen equivalent of 20/20). As Figure 4 shows, DDT decreases systematically with stimulus velocity. An analysis of variance showed that this decrease is statistically significant (F=120.58, df=6,228, p<.001). In addition, the point labeled "oblique" in Figure 1 shows that the DDT measured about 45 degrees is nearly 2 times that measured for upward motion at the same speed. This difference between 45 degrees and upward directions of motion is reminiscent of the meridional effect observed for stationary targets (SEKULER, 1974).

The DDTs measured in this study provide baseline data for the assessment of our ability to improve discrimination performance. But before proceeding to that assessment, we needed to perform some control measurements. These control measurements were designed to elucidate the character of the discrimination that observers were making in Experiment I.

EXPERIMENT II

ARE DDTs BASED ON CONSTANT DISTANCE MOVED?

Several theories of motion perception attribute our ability to judge direction to processes that resemble those involved in perception of static targets and judgments of their orientation. For example, BONNET (1975) reduced motion perception to the detection of a constant amount of displacement. In such a theory, the observer must wait until the target moves for this criterion distance before motion is perceived. We wish to determine whether a similar explanation was appropriate for the data displayed in Figure 4. In other words, it is possible that the improvement in DDT with increase in velocity was simply due to the fact that, with a constant 360 msec. exposure duration, targets that moved faster would move through greater distances during the observation interval. Presumably the observers could use this greater distance travel as an aid to judging direction. To test this notion directly, Experiment II was performed. The origi-

computer program that ran Experiment I was modified to produce durations of target motion that would be inversely related to their speed. This arrangement allowed us to measure DDTs under conditions where targets, regardless of their speed, would move a constant distance for each presentation. If the relationship between stimulus velocity and DDT (Figure 4) was an artifact of the varying distances traveled by stimuli of different velocities, measurements made with constant distance in the present experiment should reveal no relationship between DDT and target velocity. The speeds and corresponding durations used were: 0.5 degrees per second for 1517 msec., 1 degree per second for 758 msec., 2 degrees per second for 379 msec., 4 degrees per second for 190 msec., and 8 degrees per second for 95 msec. For all of these conditions the total extent of the movement in each presentation was 0.758 degrees of visual angle. Three observers were tested (chosen from the original sample of 39 observers). Each was tested in three tracks for the conditions of this experiment; in addition, the three observers were retested on the conditions of Experiment I.

The results are displayed in Figure 5. The curve labeled "duration constant" shows data for the three observers measured under conditions exactly like those used in Figure 4. All stimuli were presented for 360 msec., regardless of target velocity. The curve labeled "distance constant" showed data collected under conditions where the movement extent per presentation was constant at 0.758 degrees. The lack of appreciable difference between the two sets of data suggests that the functions shown in Figure 4 were not an artifact of the covariation between stimulus velocity and distance traveled in Experiment I. As a result, we believe that DDT varies with velocity in a direct fashion and that this relationship is not mediated by the usual covariation between distance traveled and stimulus velocity. This result is inconsistent with BONET's theory of motion perception.

Having established the validity of the covariation between DDT and target velocity, we turn to an experiment designed to improve DDT by appropriate training.

EXPERIMENT III

REACTION TIME TRAINING PROCEDURE

Twenty-five observers were chosen from those used in Experiment I. Of the twenty-five, 10 were female and 15 were male (average age 20, average visual acuity 20/20). Subjects participated in two interleaved tasks. One was the determination of DDT, identical to that used previously; the other was a novel, reactions task (hereafter RT task). This RT task was similar to that described in the introduction to this report and was that used by SEKULER & BALL (1979). In the RT task, observers were required to make reaction time to the onset of motion following exposure to 2-3 seconds of random oscillations of dots on the CRT (SEKULER & BALL 1979). The observer pressed a tele-

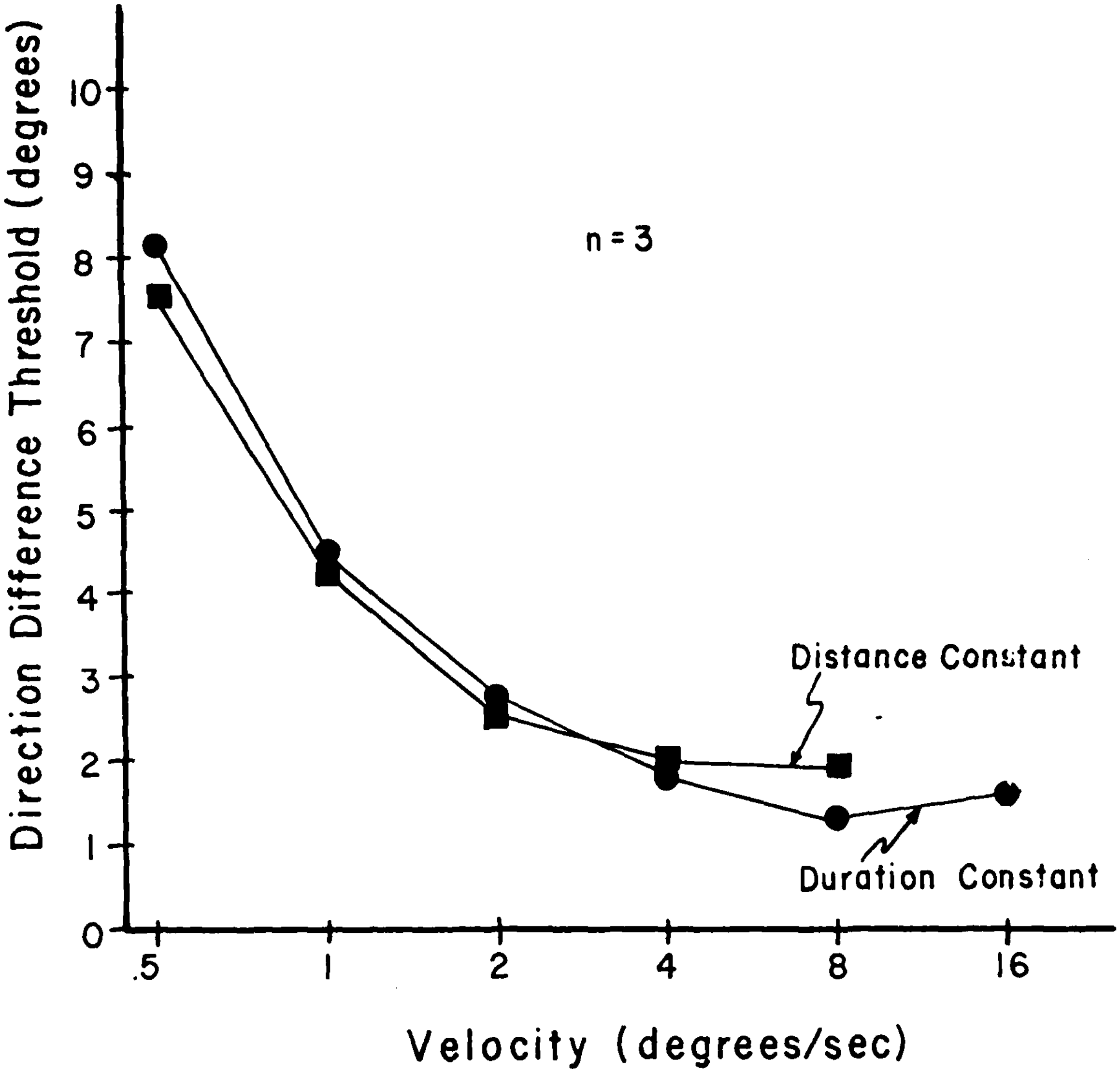

Figure 5. Direction difference thresholds as a function of stimulus velocity for conditions of constant distance traveled per exposure and for constant duration.

graph key as soon as the dots began moving uniformly in one direction. A special procedure was used to insure that the observer responded with a high degree of motivation. If the observer made reaction times within a criterion range of time, he heard a beep upon pressing the switch. This audio feedback was adjusted from day to day to insure an increasing level of motivation. On the first day of testing, the observer had to react under 999 msec; the second day within 799 msec; the third day within 599 msec; the fourth within 399 msec and on the fifth day of testing, the observer had to respond within 299 msec in order to get the audio feedback.

Observers were divided into three groups. One group (hereafter 90 degree group) was tested in the RT task with upward motion. A second group (hereafter 45 degree group) was tested in the RT task with movement in the direction of 45 degrees. A third group (hereafter 270 degree group) was tested in the RT task with downward motion, that is 270 degrees. The 90 degree group contained 9 observers while the other two groups each had 8.

The 90 degree and 45 degree groups were each tested in five different randomly ordered RT conditions. These conditions are defined by the characteristics of the oscillation of the dots that preceded the onset of the movement to which they were to react. In the one condition (hereafter uniform oscillation) the dots oscillated randomly in all possible directions. This oscillation has been described earlier in the introduction to this report,as well as in SEKULER & BALL (1979). In the other four conditions the oscillations were filtered by the computer, preventing oscillations within a particular band of directions. Two different band widths (50 degrees and 100 degrees) were factorially combined with two different center directions (45 degrees and 90 degrees). Thus four conditions of filtering were used. A 270 degree group participated in the same number of trials as the other two groups but was tested only with uniform oscillation.

Each session consisted of 50 trials of oscillation followed by reaction time to the direction of motion for the particular group (that is either 90 degrees for the 90 degree group, 45 degrees for the 45 degree group, or 270 degrees for the 270 degree group). The first 10 trials in a block were considered practice and were not subjected to further analysis. Each observer participated for five successive days. The schedule was as follows:

Day 1: DDT measurement
RT task
Day 2: RT task
Day 3: RT task
DDT measurement
Day 4: RT task
Day 5: RT task
DDT measurement

All moving targets had a velocity of 4 degrees per second.

Consider first the results of the reaction time task. RT to 4 degree per second motion on Day 1 following *uniform* oscillation was 398.90 msec. Over the course of the 5 days of testing this mean dropped successively:to 380.90 on Day 2 to 378.11 on Day 3, to 349.94 on Day 4 and finally down to 326.46 on Day 5 (corresponding standard errors were 22.95, 23.89, 24.98, 11.41, and 18.65 msec). Control measurements with other observers (SEKULER, 1980) indicate that had the oscillation not been present, the mean reaction time to this velocity of motion would have approximately been 250 msec. The difference between reaction times measured here in Experiment III and those determined earlier reflect the masking produced by the oscillation. This masking reduces the visibility of the motion, thereby delaying reactions to its onset. Note that over the course of the 5 days of testing the effect of the masking decreased by approximately 70 msec. We believe that this is in part due to the motivational aspects introduced by the decreasing criterion reaction time in order to get feedback on each trial in the form of the auditory signal.

In contrast to this systematic change in overall reaction time as a function of day of testing, the training itself seemed to have little effect. For example, the differences between filtered and unfiltered conditions changed reaction time by only 7 per cent at most and did so in a non-systematic way. This was very disappointing considering that BALL & SEKULER (1979) had found appreciable effects of the degree of filtering. See Table 1.

Turn now to the consideration of the DDT measurements. Figure 6 shows DDT as a function of velocity for the 90 degree group. The parameter of the family of curves is day of measurement. As indicated previously, DDTs were measured for upward motion. Two important points need to be made here. First, there are no appreciable differences from Day 1 to Day 5 in the DDT. Second, the DDTs represented in Figure 6 are virtually identical to those shown in Figure 4 for the larger group of observers. Figure 7 shows comparable data for the 45 degree group. Again, with the exception of the slowest velocity used, the data here are virtually identical to those shown in Figure 4. Moreover, the 45 degree group also fails to show an effect of day of test. Figure 8 shows comparable data for the 270 degree group. This group too fails to show effect of day of testing. We believe that variation from group to group (Figures 6-8) at the slowest velocity used (0.5 degrees per second) simply reflects sampling differences. In other words, each of the three groups shown in Figures 6-8 are a sample of observers from the original, larger group of 39 observers. We do not think that the small differences among the three groups at the slowest speed used reflect the effects of training. This is consistent with the fact that the DDT measurements on Day 1 (Figures 6-8) were actually made before the groups were treated differentially.

Table 1

Reaction Times for 90° and 45° Groups

	Day of Testing					
	1		3		5	
Notch:	None	100°	None	100°	None	100°
Group						
90°	410.3 (12.6)	401.9 (11.9)	369.3 (5.7)	362.9 (5.3)	323.9 (4.6)	318.3 (7.0)
45°	412.9 (8.6)	384.4 (4.2)	404.4 (11.5)	374.9 (11.7)	335.9 (11.4)	315.1 (7.8)

Note: Values without parentheses are group means; values inside parantheses are standard errors. Data for the 100° notch are those for which the notch is centered on that group's test direction, i.e. on 45° for the 45° group and on 90° for the 90° group.

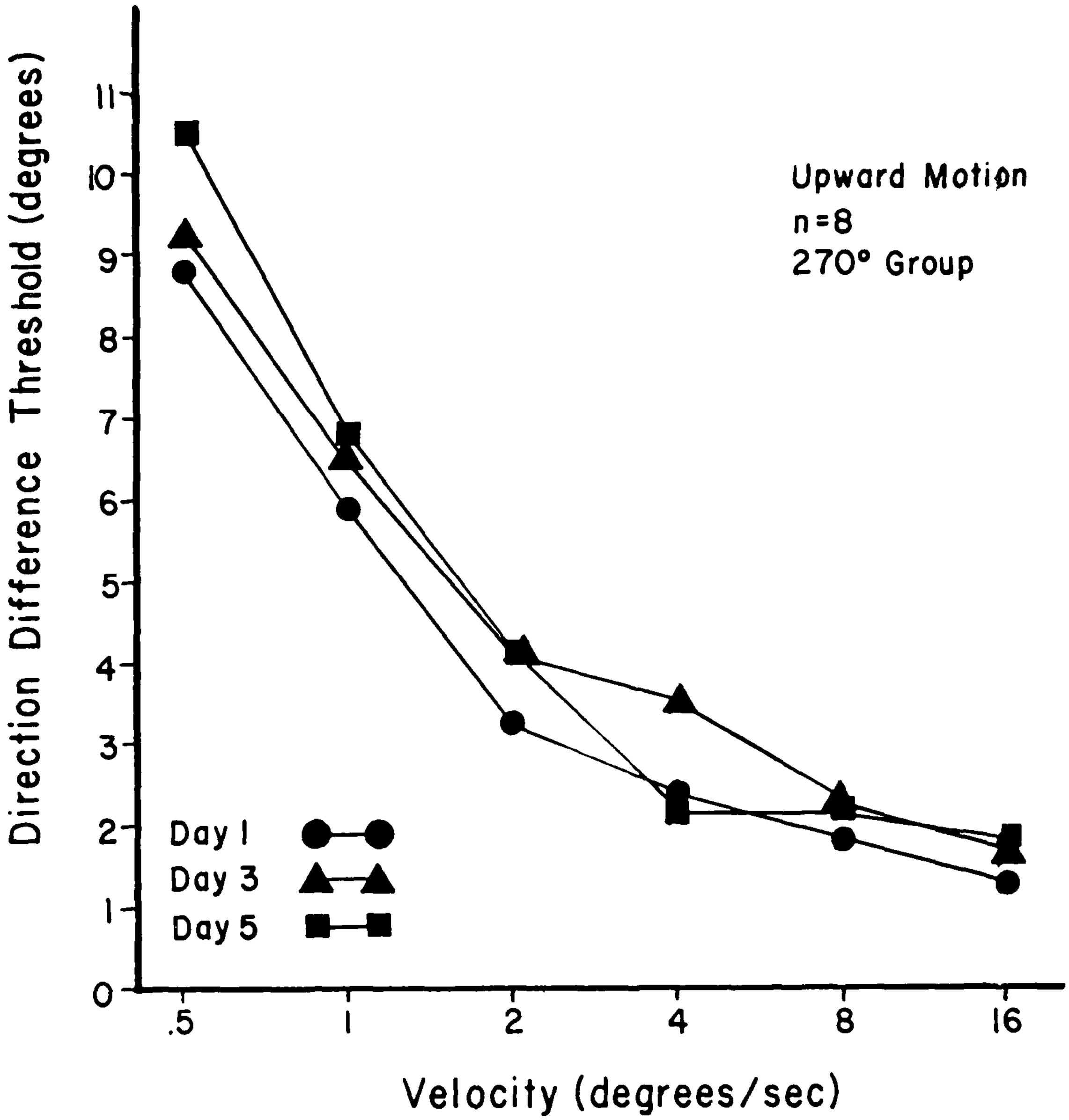

Figure 8. Direction difference thresholds as a function of stimulus velocity for the 270^{o} group. The parameter of the curves is day of testing.

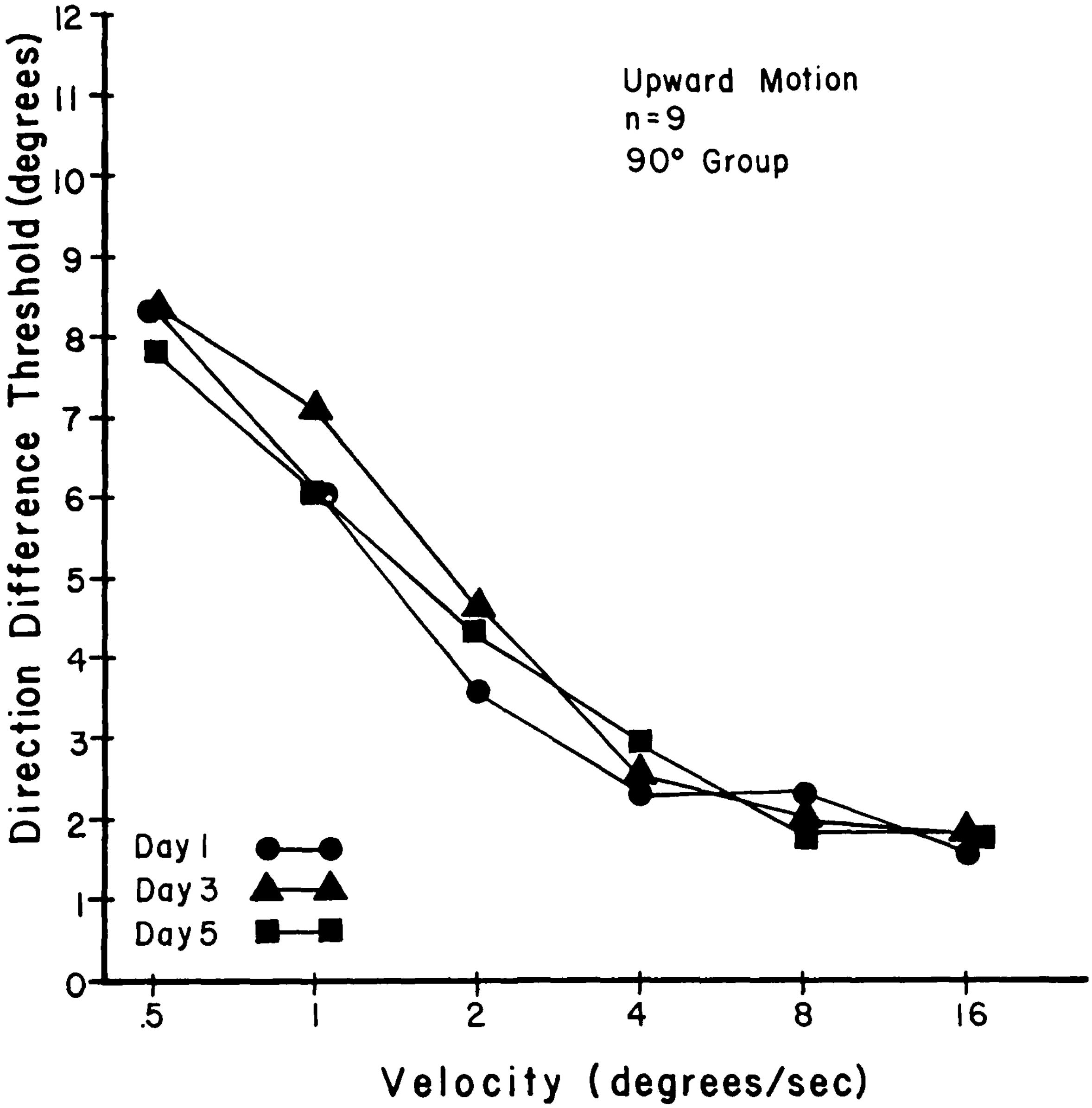

Figure 6. Direction difference thresholds as a function of stimulus velocity for the 90° group. The parameter of the curves is day of testing.

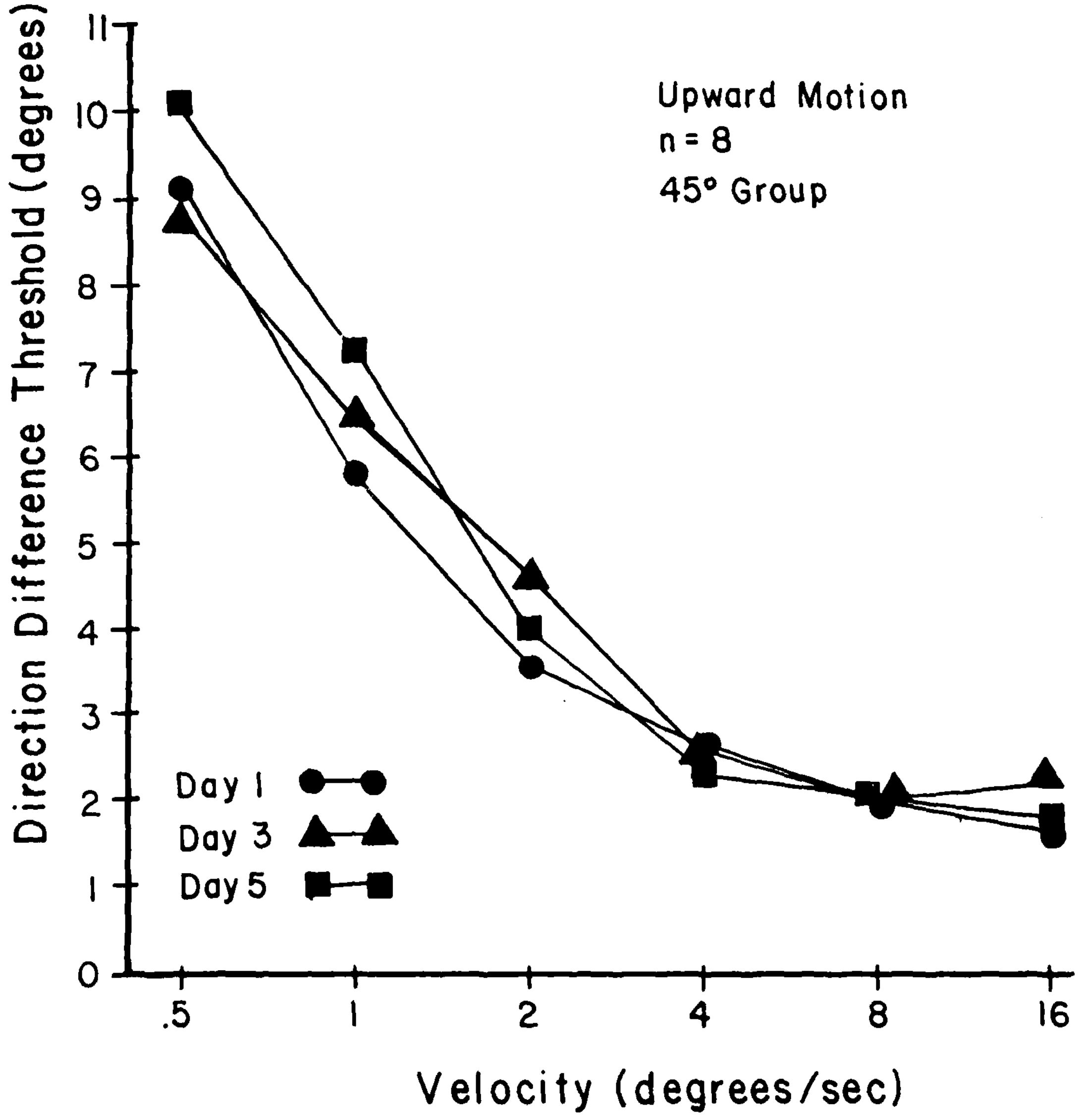

Figure 7. Direction difference thresholds as a function of stimulus velocity for the 45° group. The parameter of the curves is day of testing.

In order to determine whether individual observers may have changed systematically in their DDTs over time, we looked at individual subjects' performance. Figure 9 shows the method used for one of these analyses. Figure 9 shows individual DDTs measured at 2 degrees per second for 45 degree group. In this case, DDTs were measured around an oblique direction, the same direction of motion to which this group was required to make its reactions in the RT tasks. Of the 8 observers in the group we identified 4 who showed at least some decrease in DDT over days. These 4 observers were retested one month later in order to see whether the decrease in DDT was or was not preserved. The results of these measurements are shown in Figure 10. The left hand data points in Figure 10 are the measurements made for these 4 observers in Experiment I (that is, they are part of the work contained in Figure 4). Note the substantial individual differences on the pretest. One observer has a DDT more than twice that of any of the others. By the third day of testing that observer decreased his DDT to approximately that of the other observers. Most important though is the fact that when tested 1 month following Day 5 of training, 2 of the observers retained the decrease in DDT produced over the three days of training, while the other 2 observers failed to retain that improvement. Although this improvement is not an impressive demonstration of the efficacy of the training procedure, at least for the observer who started off (Figure 10) with the largest DDT, there does seem to be an appreciable effect of practice on this task. His final DDT, one month after training, is only one fourth that of his initial level.

The lack of practice effect for most observers is shown clearly in Figure 11. Each cluster of 3 histogram bars defines the mean performance over days for one of the three groups of observers. The ordinate shows the DDT. Data are shown in this figure only for test velocity of 4 degrees per second but the same picture emerges for the other test velocities as well. Note that there is no indication of a systematic decrease in the DDT with day of practice for any of the three groups. Over the course of the 5 days of practice, each observer performed the RT task 250 times per day. Thus, over the entire course of training each observer performed the RT task more than 1200 times. Clearly, even as many as 1200 or more trials of speeded response to the same moving target fails to improve the precision which the average observer is able to judge the direction of movement. In other words, the DDT is virtually unaffected by more than 1200 trials of distributed practice with the reaction time task.

EXPERIMENT IV

CAN PRACTICE REDUCE THE EFFECTS OF DIRECTION UNCERTAINTY?

Previous work in this laboratory has shown that one of the serious limitations on performance in tasks involving detection of motion

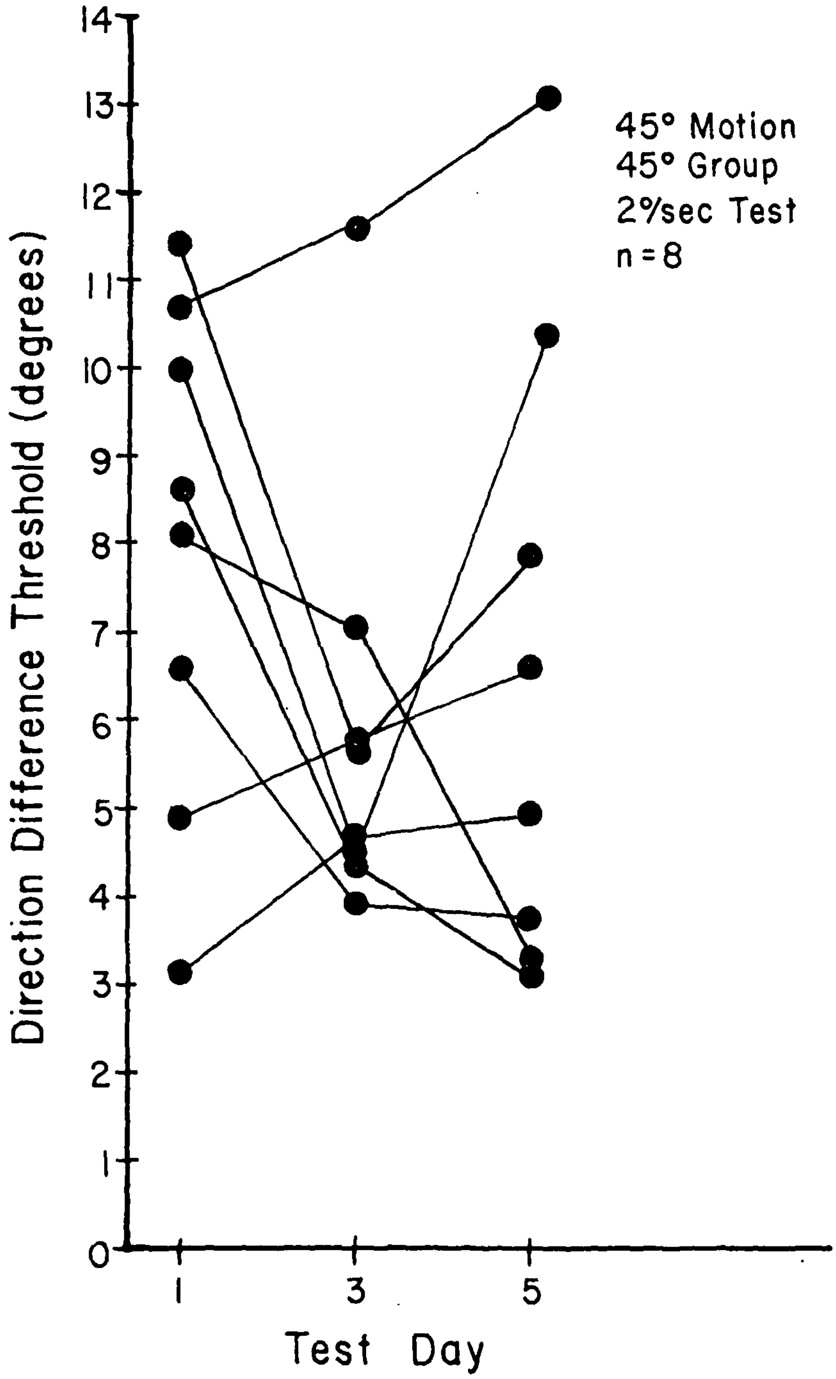

Figure 9. Direction difference threshold for various test days. Data shown are for individual observers in the 45° group. Stimuli moved obliquely at 2° per second.

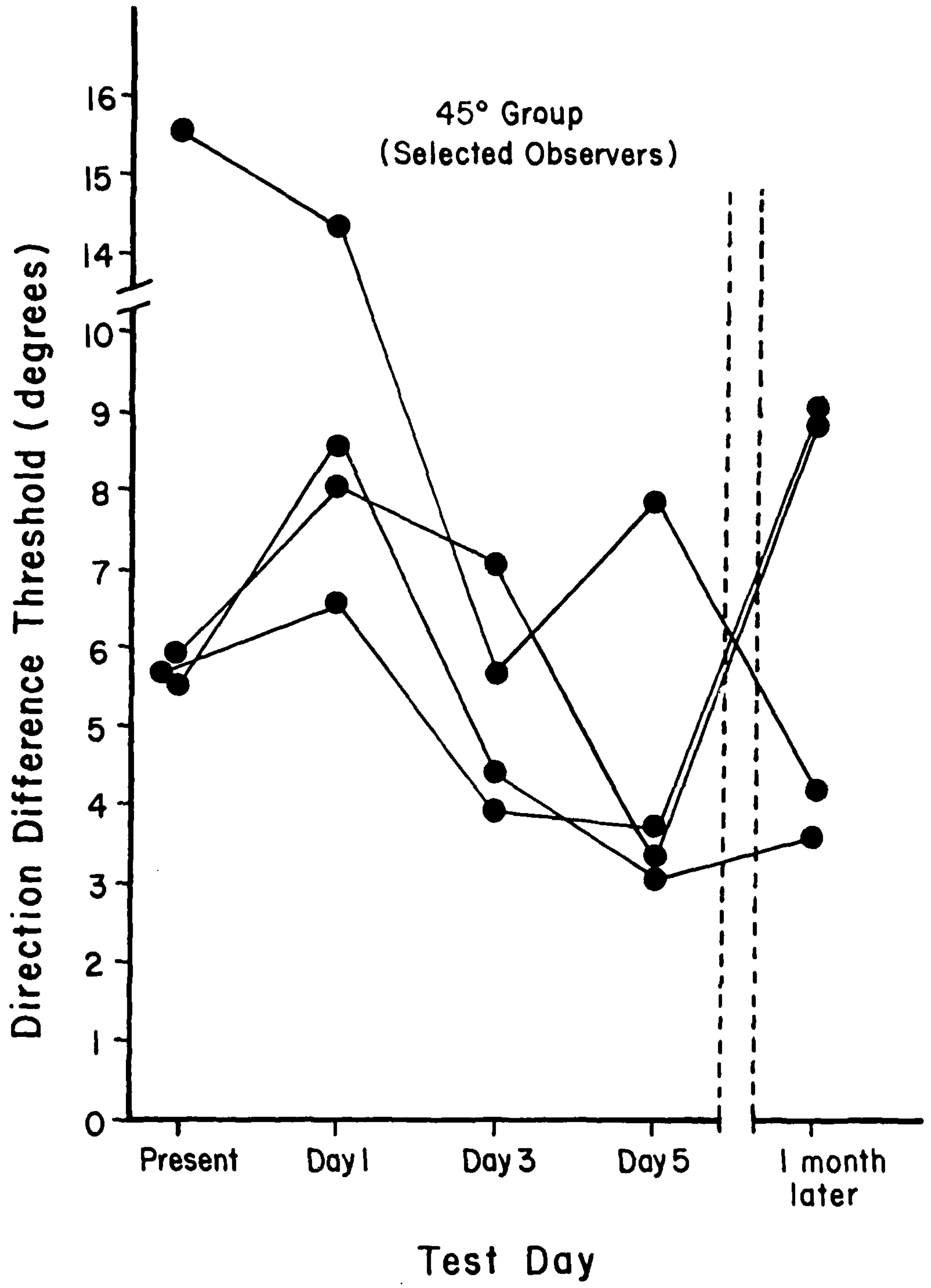

Figure 10. Direction difference threshold as a function of test day for selected observers from the 45° group. Notice the split in the ordinate between 10° and 14°, as well as the split in the abcissa between Day 5 and the one month followup.

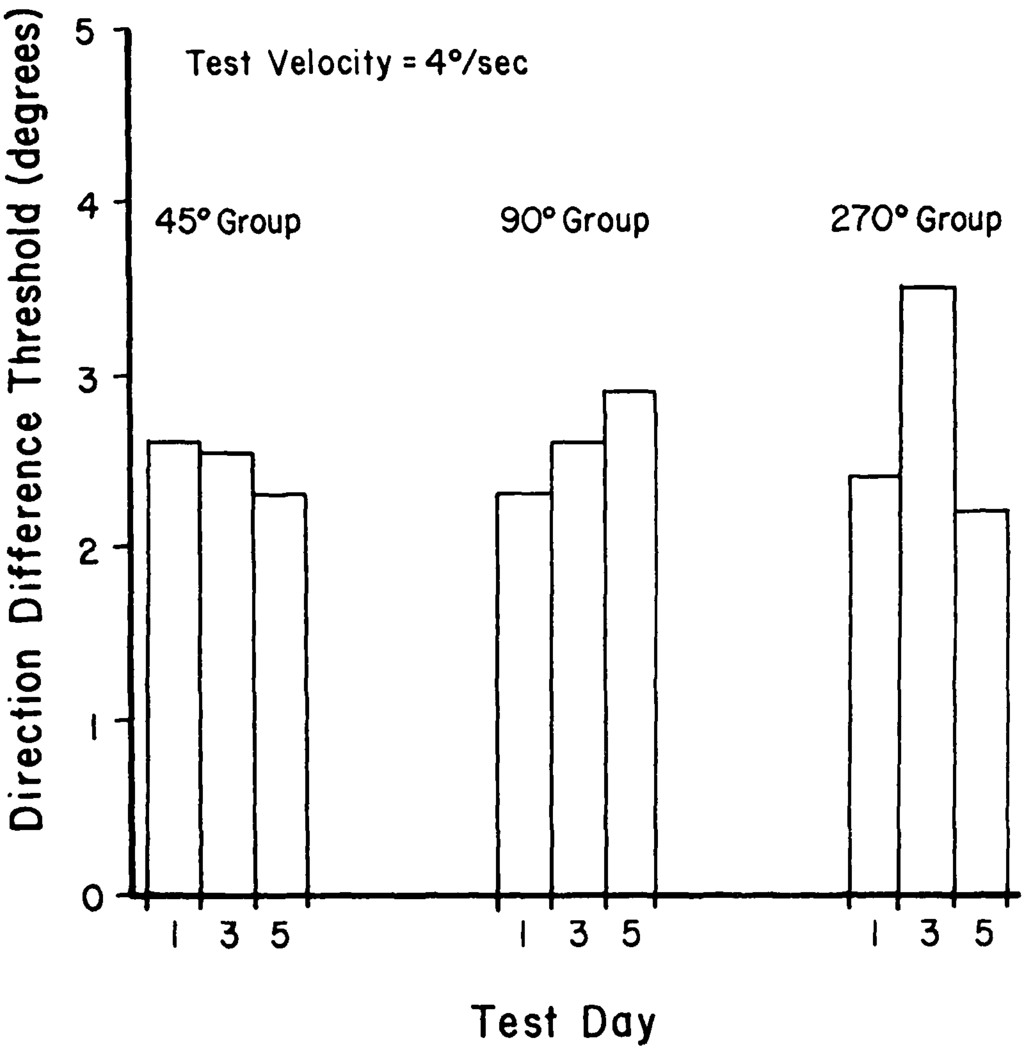

Figure 11. Direction difference threshold as a function of day of test for each of the three test groups. Test velocity was 4 degrees per second; data are means for observers in each group.

is the observer's uncertainty about the direction that he is to detect (SEKULER & BALL, 1977). But the effects of uncertainty have not been found to uniformly affect performance in all stimulus domains. For example, SHIFFRIN and his colleagues (SHIFFRIN & GRANTHAM, 1974) failed to find effects of uncertainty in tasks including visual spatial location, dot detection, spatial location on the skin and recognition of speech-like syllables. One possible difference between results retained by SHIFFRIN and our own results using moving stimuli was the practice that SHIFFRIN's observers received prior to testing.

In his studies, two conditions were compared: 1) a simultaneous condition in which the observer had to detect any of n possible signals, and 2) a sequential condition in which the same n signals could occur but did so only one at a time and in an order known to the observer during n successive temporal intervals. SHIFFRIN and his colleagues found no differences in any of their experiments between simultaneous and sequential test conditions. Note that in the sequential condition, so long as the observer could keep track of which interval he was in at any moment, uncertainty as to target condition would be basically zero. In other words, the failure to find a difference between simultaneous and sequential test conditions in SHIFFRIN's experiments suggested a lack of effect due to target uncertainty. We decided to compare performance on simultaneous and sequential presentations in the domain of motion.

Three graduate student volunteers (mean age 23; mean visual acuity 20/20) were tested. Dot luminances were adjusted so to permit approximately 75 per cent correct identification of the the interval containing motion when used in a two alternative forced-choice procedure (SEKULER & BALL, 1977). This 75 per cent correct performance was achieved in the absence of direction uncertainty. That is, all measurements leading to the determination of this luminance value were made with upward moving targets.

On each trial, one and only one of four possible directions of motion was presented. Directions were selected randomly under the constraint that in a block of 48 trials, all directions appeared equally often. The four possible directions were 90, 180, 270 and 360 degrees. Intervals during which dots might appear were defined by a tone.

Three conditions were compared. In the Simultaneous Condition, ~~a~~ trial consisted of one, 600 msec long interval. During this interval one of the four possible directions of motion was presented. The observer's task was to indicate in which direction the movement occurred. For reasons not directly related to this report observers also made a second guess -- that is, they also indicated

what direction seemed next most likely to have occurred. Feedback was provided in the form of one tone if the first choice of direction was correct and two tones if the second choice was correct.

A trial in the Squential Condition consisted of four successive, 600 msec intervals separated by 700 msec. Although only one direction of motion actually occurred on each trial in the Sequential Condition, there was a regular and fixed relationship between the order of observation intervals and the direction that could occur in each. Going from the first to the fourth observation interval, the possible directions varied clockwise, from upward through leftward. In other words, 90 degrees was the only direction eligible to appear in the first interval, 360 the only one for the second interval, 270 for the third interval and 180 for the fourth. A cue, in the form of a line, was presented prior to each of the intervals to remind the observer of the direction of movement possible for each interval. The cue was presented 700 msec before each test interval. Note that direction uncertainty was eliminated by the combination of cue before each interval and the regular relationship between the order of intervals and the eligible directions. The observer's task was to indicate in which direction the movement occurred. First and second choices were again recorded and feedback provided. Thus this condition used a four-alternative forced-choice procedure in which only one interval contained a moving target. The other three intervals were blank.

A trial in the third, Random Condition consisted of four successive intervals like those of the Sequential Condition. However, there was no correlation between the order of intervals and the direction of possible movement and no cue was provided before each interval. Movement was presented in only one of the intervals, and the observer's task was again to indicate in which direction movement occurred. First and second choices were recorded and feedback was provided. Note that both the Random and Simultaneous Conditions involve direction uncertainty but that the Sequential Condition does not.

Figure 12 shows d' as a function of session number. The d' metric was used to facilitate comparisons among the various test procedures.

We shall be primarily concerned with d' values based on first choice responses for all three conditions. Performance in the Sequential Condition was superior to that in the Simultaneous and Random Conditions for all observers. Mean d's were 1.31, 0.34, and 0.31, for Sequential, Simultaneous, and Random Conditions, respectively. An analysis of variance confirmed the statistical significance of these differences ($F=17.36$, $df=2,4$, $p<.025$). A subsequent Newman-Keuls test showed that the Sequential Condition was significantly better than either the Simultaneous or Random Conditions ($p<.05$). In other words, the condition (Sequential) that permitted the observer to be certain about the direction to be presented produced better performance than either of the two uncertainty conditions; the two uncertainty conditions (Simultaneous and Random)

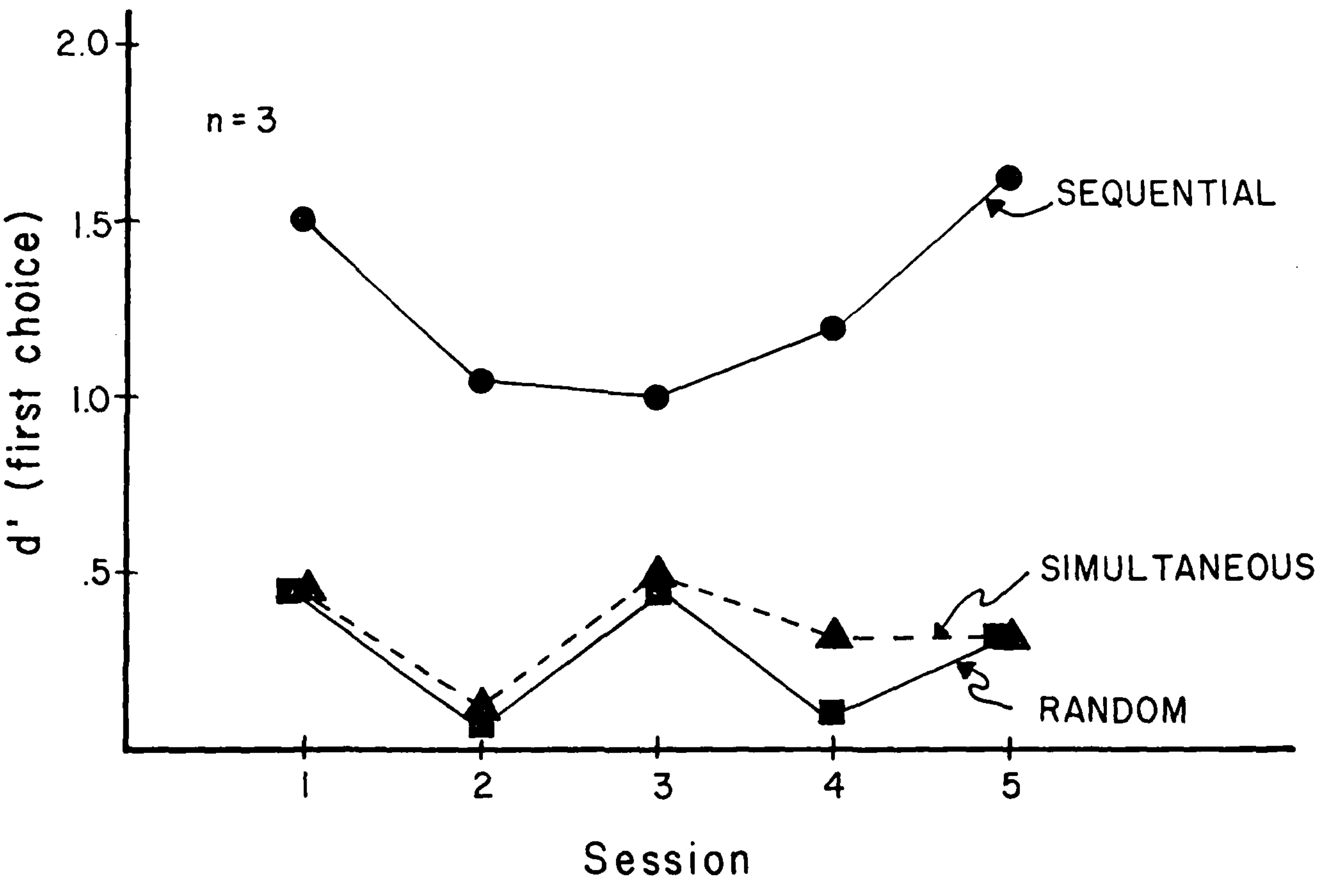

Figure 12. d' as a function of test session for the three conditions used in Experiment IV.

produced essentially equivalent performance losses. The analysis of variance showed no significant effect of test session (F=.39, df=2,4, p>.50).

We also analyzed the observers; second choices for each trial. Contrary to the outcomes in other second choice experiments (SWETS, 1961), in all three experimental conditions, the observers' second choices were never better than chance performance, approximately 33 per cent correct.

A single-band model of direction perception (SEKULER, 1980) assumes that only one direction can be monitored on a given trial. This means that performance in the Simultaneous and Random conditions should equal that of the Sequential condition on only 25% of the trials. For the remaining 75% of the trials the single-band model predicts performance in the Simultaneous and Random conditions *equal to chance*. The multiple-band model predicts that performance in the Simultaneous and Random conditions will be equal to the d' obtained in the Sequential condition divided by the square root of 4 (the total number of alternatives). See SEKULER, 1980 for a full treatment of these models.

The predictions for the Simultaneous and Random conditions from the different models are presented in Table 2 along with the obtained d' values for all three conditions. Note that in general the data seem most consistent with the single-band model. Thus in this experiment observers appear to be capable of monitoring only one of the four possible direction-selective mechanisms on a given trial, even following practice over five sessions. More significantly for the present concern, however, is the fact that the observers' performance -- and the effect of direction uncertainty -- is stable over 5 days' practice.

Table 2

Predicted and Obtained d's for Experiment IV

Session	Single-band	Multiple-band	Simultaneous	Random
1	0.42	0.76	0.45	0.45
2	0.32	0.58	0.11	0.11
3	0.23	0.52	0.51	0.48
4	0.32	0.61	0.32	0.18
5	0.35	0.65	0.34	0.31
Mean	0.35	0.65	0.34	0.31

EXPERIMENT V

Psychoacoustics has provided much anecdotal evidence that practice may produce dramatic results on tasks involving stimulus uncertainty effects (MORAY, 1969). But these reports have not been followed up systematically. That practiced observers can learn to do complex perceptual tasks impossible for the beginner (NEISSER, 1976), is less surprising than the fact that practice affects seemingly simple, detection tasks. Why, for example, is there improvement in simple, visual detection over as much as four months' practice with the same stimuli (TAYLOR, 1964)?

In one of the best known demonstrations of practice effects in perception, NEISSER, NOVICK and LAZAR (1963) found that after several weeks' practice, observers could search for any of 10 possible targets as rapidly as for just one, previously specified target. In other words, subjects learned to overcome the harmful effects of stimulus uncertainty.

This experiment was designed to provide observers with extensive practice on a task known initially to produce substantial uncertainty effects. Experiment IV failed to reveal improvement in motion detection with practice under conditions of uncertainty. Experiment IV involved an extreme amount of direction uncertainty: the directions that <u>might</u> occur covered the entired range of 360 degrees. Practice <u>did not</u> help under such conditions. But it is possible that observers might be aided by practice in connection with a <u>smaller</u> amount of uncertainty. So Experiment V used smaller ranges <u>of uncertainty</u> and sought to determine whether practice could substantially improve detection.

The observers, apparatus, and stimuli were the same as in Experiment IV. As before, for each observer we first found the dot luminance that produced about a criterion correct two-alternative forced-choice performance when target motion was exclusively upward. This time, however, the criterion level was 90% rather than 75%.

Five stimulus alternatives were equally likely on each trial. In all cases, the five stimuli were evenly spaced along the direction continuum. Moreover, the middle stimulus of the five always consisted of upward (90 degree) motion. The range of directions covered by the five stimulus possibilities constituted the three conditions of the experiment. The narrowest range covered 40 degrees, with possible directions of 70, 80, 90, 100 and 110 degrees. The middle range covered 80 degrees, with possible directions of 50, 70, 90, 110, and 130 degrees. The widest range covered 120 degrees, with possible directions 30, 60, 90, 120, and 150 degrees. All directions within a range occurred with equal frequency but in a random order. As before, the observer merely had to indicate which interval, first or second, contained motion.

To assure a high level of motivation, observers were paid 2 cents for each correct response; 1 cent was deducted for each incorrect response. These payoffs were in addition to the hourly pay. A tone sounded after each correct response.

The experiment consisted of five stages: pretest, practice, test 1, practice, and test 2. In any of the test phases (pretest, test 1, test2), 2-AFC measurements were made under each range of uncertainty: narrowest (40 degree), intermediate (80 degree), and broadest (120 degree). Order of testing with various ranges was randomized and consisted of 2 blocks of 50 trials under each Uncertainty Range. The practice phases consisted of 15 blocks (50 trials each) of 2-AFC testing with just the 120 degree uncertainty range. Before any block of trials, the observer was told what the range would be for that block.

From each block of 50 trials, we calculated percent correct identification of the intervals that contained motion. These percent correct values were transformed into the $\underline{d}'$ values shown in Figure 13. To make interpretation less ambiguous, we did separate analyses of variance on the data from each of the three phases of the experiment: pretest, first test, and second test. For measurements made in the pretest phase, before the subject had received practice, Range of Uncertainty was a significant source of variance ($\underline{F}=7.5$, $\underline{df}=2,4$, $\underline{p}<.05$). As expected, performance was poorer when the possible directions of movement were spread over a wider range.

A separate analysis of variance was performed on the $\underline{d}$'s for test 1 and test 2 (that is, following 750 and 1500 practice trials with the 120 degree range condition). The analyses showed that Uncertainty Range was not a significant source of variance during either the first or the second test phase ($\underline{F}=2.79$, $\underline{df}=2,4$, $\underline{p}<.05$; $\underline{F}=0.68$, $\underline{df}=2, 4$, $\underline{p}>.50$).

It appeared from the data that practice trials on the 120 degree range condition improved performance (especially for that range). This finding called for a further analysis. A two-factor analysis of variance was done in which range of uncertainty and performance on the three test phases were the variables. Significant effects were noted for both the range and test phases ($\underline{F}=30.69$, 8.44, $\underline{df}=2,4$, $\underline{p}<.05$). More importantly, however, the interaction between the range and test variables was significant ($\underline{F}=3.99$, $\underline{df}$-4,8, $\underline{p}<.05$) indicating that the difference between the three different range conditions in the pretest phases was eliminated following practice.

Experiment V shows that repeated testing reduces detection losses normally associated with direction uncertainty. When pretest performance was measured, observers did significantly more poorly with the larger ranges of possible directions than with the narrower range. But by the first test, there were essentially no differences among the three range conditions.

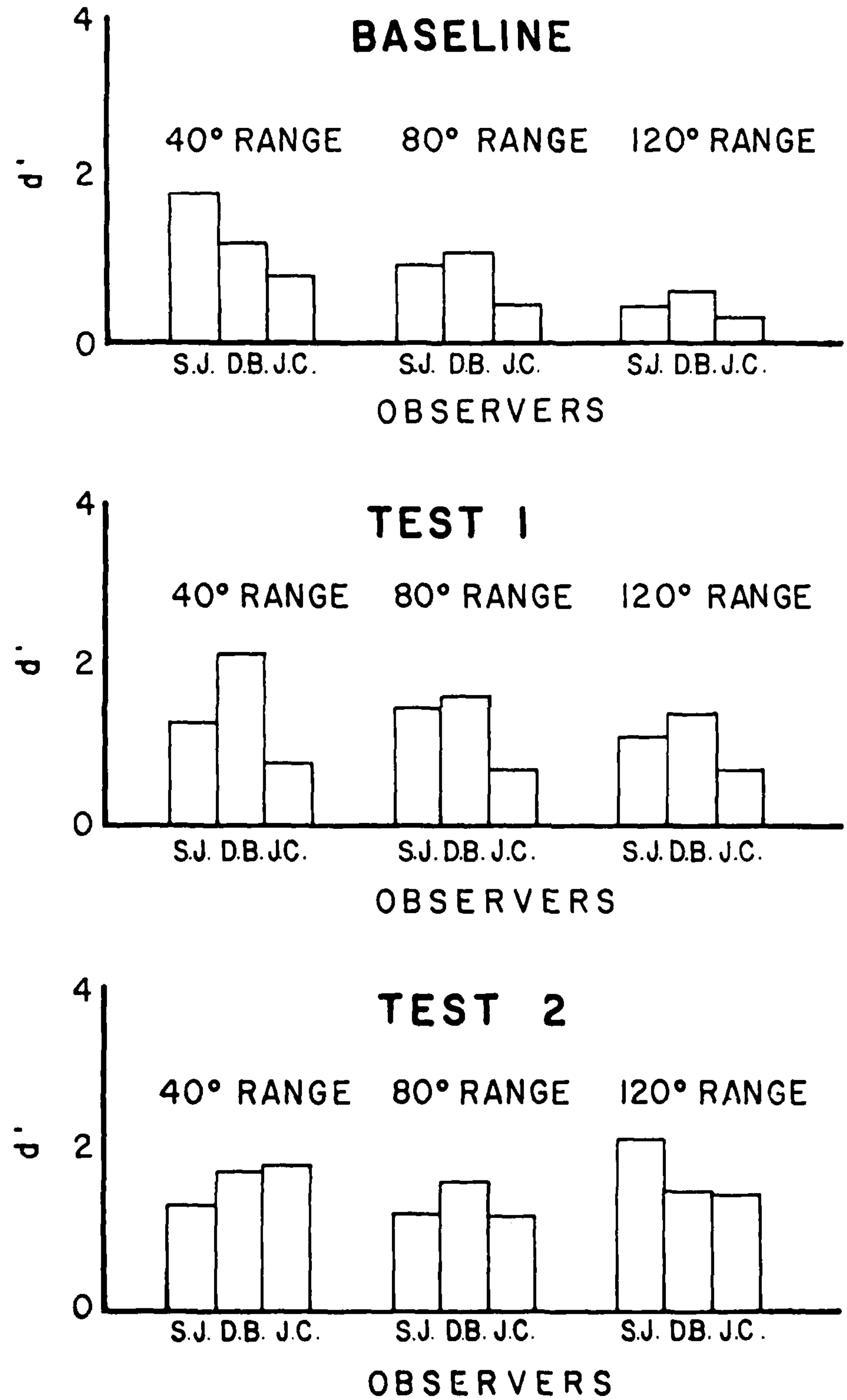

Figure 13. d' for individual observers in Experiment V. Top panel: results from pretest; middle panel: results following first practice sessions; bottom panel: results following last practice sessions. Within each panel, data are shown for three different uncertainty ranges.

We should note that there are distinct limits to the improvement in performance. Although the differences among the three uncertainty ranges disappeared with practice, an overall effect of uncertainty remained. For example, the final mean d's for the three uncertainty ranges were: 1.66, 1.34 and 1.66 for 40^o, 80^o and 120^o ranges respectively. All three of these performance levels were considerably below the mean d' measured under conditions of certainty (all movement upward) at the end of the experiment: d'=2.32. For readers more familiar with the percent correct metric, these values correspond to 88%, 83% and 88% for the three uncertainty ranges and to 95% for the certainty case.

FUTURE DIRECTIONS

The results of Experiment V are particularly encouraging: when the proper conditions obtain, it is possible to enhance certain aspects of motion sensitivity with appropriate training. Just as encouraging is the fact that such improvement occurs rapidly. Obviously we still need to determine the boundary conditions for this improvement: how long such improvement is retained and the extent to which improvement generated under one set of target conditions transfers to other conditions.

ACKNOWLEDGMENT

This research was performed at the Cresap Neuroscience Laboratory, Department of Psychology, Northwestern University under grand AFOSR-79-0064 from the Air Force Office of Scientific Research. Robert Sekuler was the Principal Investigator. Major Jack Thorpe and Dr. Genevieve Haddad were the scientific monitors for AFOSR, and Captain Arthur Ginsburg of the USAF Aerospace Medical Research Laboratory provided scientific guidance.

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